International Journal of Engineering and Advanced Research Technology (IJEART)
ISSN: 2454-9290, Volume-2, Issue-3, March 2016

Based on the thermal insulation pipe eccentricity detection of eddy current sensor design

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Abstract—**Thermal insulation pipe eccentricity detection has important influence on the service life of anti-corrosion insulation pipe. But eccentric detection using wide-range eddy current sensor is less and in high prices. Based on Biot-Savart Law, the analytic design for eddy current sensor; Using electromagnetic field numerical analysis methods, the analytic design of the coil parameters for the numerical analysis, analysis results are consistent with the results of analytical design. In order to illustrate the correctness of the analytical design method and numerical model, for the design of the eddy current sensor and the design parameters of impact analysis provide some guidance.**

***Index Terms*—Thermal insulation pipe, eccentricity detection, eddy current sensor, sensitivity.**

I. INTRODUCTION

Insulation pipe is along with the crude oil production for a long time, Daqing oil field, Tarim oil field, Xinjiang oilfield such as major oil fields have entered after heavy oil production period, can carry on the insulation to the heavy oil transportation pipeline, mainly by the yellow jacket, polyurethane foam layer, coating, pipe form [1]. Polyurethane foam layer- insulation layer, the uniformity of the thickness of insulation pipe heat preservation effect, life has a decisive influence. However, in the process of production, pipeline of the center axis of motion and yellow jacket in the right center axis, eccentric problem lead to uneven thickness of insulation layer. Therefore, in order to ensure the quality of thermal insulation pipe production and the use of thermal insulation pipe effect is good, need to be eccentric test. In thermal insulation pipe eccentricity detection, heat pipe is miles away, a total of four layers of tubular structure, the outer surface is yellow jacket protective layer, thickness is about 3 mm, the middle is made of polyurethane foam thermal insulation layer, its thickness is not less than 25 mm (GB50538-2010) [2], the inner layer is the coating thickness is about 2 mm, the layer is the most 8 mm wall thickness, ranging between 60 to 219 mm diameter pipes, as shown in Fig 1.

In GB50538-2010 of eccentricity 5 mm[2], therefore, when the eccentricity are detected using eddy current sensor, the sensor probe and the distance between the range between 23 ~ 33 mm, at least, that is, the linear range of the eddy current sensor used at least between 0 ~ 40 mm, and between 20 to 40 mm with good linearity.

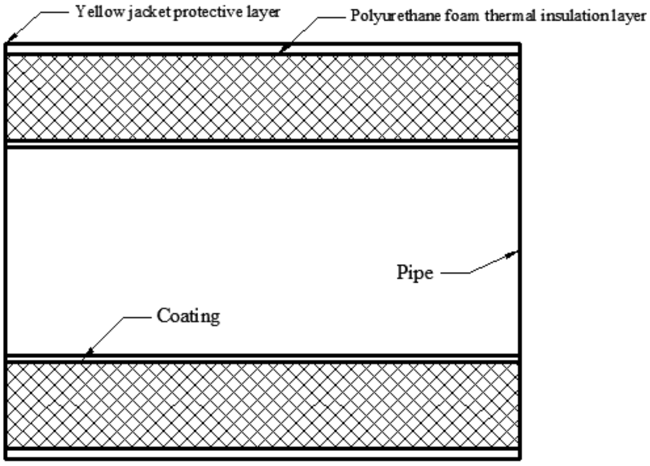

Fig 1 Insulation Tube Structure

In this paper, eccentric detection used in the eddy current sensor is belonging to the eddy current sensor in a wide range. At present, the domestic large range of eddy current sensor is less, and expensive, so it is necessary for anti-corrosion insulation pipe eccentricity detection of eddy current sensor is used in the design. This paper based on the law of Biot-Savart Law design of eddy current sensor, the second of the eddy current sensor parameters obtained in the design of electromagnetic field simulation analysis; Based on the design results and comparison of the results of numerical analysis shows that the design results are consistent with the results of numerical analysis, for eccentric test provides theory basis for the design of the eddy current sensor.

II. EDDY CURRENT SENSOR ANALYTICAL DESIGN

Eddy current sensor structure is simple, mainly composed of coil and framework. Generally adopt enameled copper wire; coil framework generally USES the small loss at high frequency, small linear expansion coefficient, good electric properties polytetrafluoroethylene, and polyimide materials. In the eddy current sensor, the main sensitive element is the eddy current sensor probe coil [3]. Size and size of coil is related to the sensitivity and linear range of the eddy current sensor, therefore, through the coil size and shape on the research on the effects of sensor sensitivity and linear range, and the requirement of eddy current sensor linear range, can preliminarily determine parameters such as the inside diameter, outside diameter and thickness of the coil.

In this study to detect eccentric eddy current sensor is measuring displacement eddy current sensor, to make the eddy current sensor linear range is big, larger scope of axial magnetic field distribution of the sensor coil [4]. Based on Biot - Savart law shows that single turn from any point on the axis of the current-carrying circular coil magnetic field intensity Bp as follows[5]:

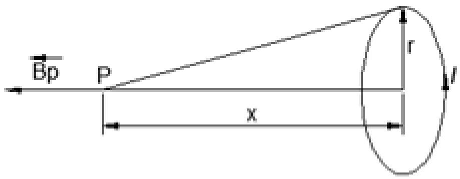

Fig 2 Single Turn Current-carrying Coil

$$Bp = \frac{\mu_0 I}{2} \frac{r^2}{\left(x^2 + r^2\right)^{3/2}} \quad (1)$$

In (1), μ_0 is vacuum magnetic permeability; r is the radius of the current-carrying coil; x is the coil center to the distance from any point on axis; I is to access on the coil current. Using MATLAB to calculate when I is a constant value, magnetic induction intensity with the change of the radius of coil, as shown in Fig 3.

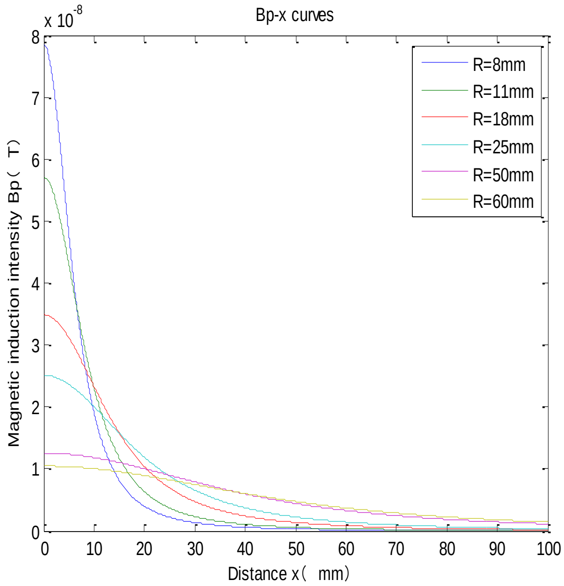

Fig 3 Coil axial magnetic field strength curve along with the change of distance

Under the same current value, the more smaller radius of coil, at the close of the magnetic field strength is the more larger, but the axial magnetic field intensity attenuated fast; Radius of coil the more larger, at the close of the magnetic field strength is more smaller, but the axial magnetic field intensity decay is slow, and in the distant place small magnetic field strength is greater than the radius of the strength of the magnetic field coil. After the figure shows that the radius of 25 mm coil axial magnetic field attenuation slower, and 60 mm to 50 mm and radius of the coil axial magnetic field strength gap is not big, therefore focuses on the coil radius of 25 ~ 60 mm within the scope of the axial magnetic field change with distance.

The Fig 4 shows that the radius of the coil is 40 mm, 45 mm, 50 mm, 55 mm, coil in the range of 20 ~ 40 mm with good linearity. So the initial outer radius of coil is 40, 45, 50, 55 mm.

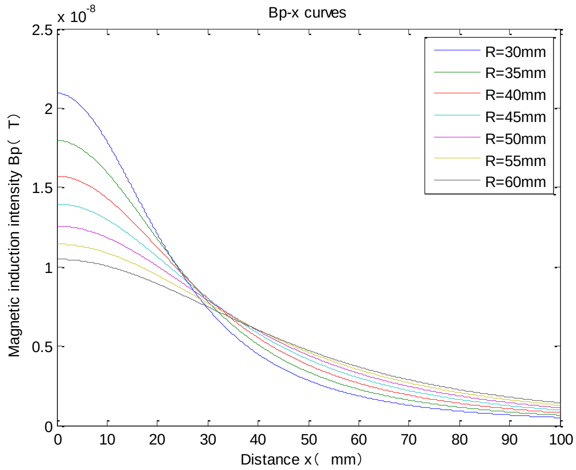

Fig 4 radius of coil within 25 ~ 60 mm axial magnetic field along with the change of distance between curves

A. Outer Radius of Coil

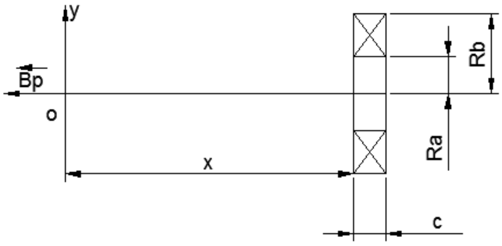

Fig 5 rectangular section coil

For routine use for rectangular current-carrying flat circular cross section of the coil, the axial magnetic field strength Bp for [6] :

$$B_p = \frac{\mu_0 NI}{2(R_b - R_a)c}\left\{(x+c)\ln\frac{R_b + \sqrt{R_b^2 + (x+c)^2}}{R_a + \sqrt{R_a^2 + (x+c)^2}} - x\ln\frac{R_b + \sqrt{R_b^2 + x^2}}{R_a + \sqrt{R_a^2 + x^2}}\right\} \quad (2)$$

In (2), μ_0 is vacuum magnetic permeability; N is the coil number of turns; I is to access on the coil current; R_b is the outer radius of coil; R_a is the inner radius of coil; c is the thickness of the coil; x is the coil center to the distance from any point on axis.

In the case of other parameters constant, change the outer radius of coil, the parameters in Table Ⅰ generation into the type of calculation, and draw its curve B - x, as shown in Fig 6.

Table Ⅰ Eddy current sensor coil parameters

Number	R_b **(mm)**	R_a **(mm)**	c **(mm)**
1	40	36	5
2	45	36	5
3	50	36	5
4	55	36	5

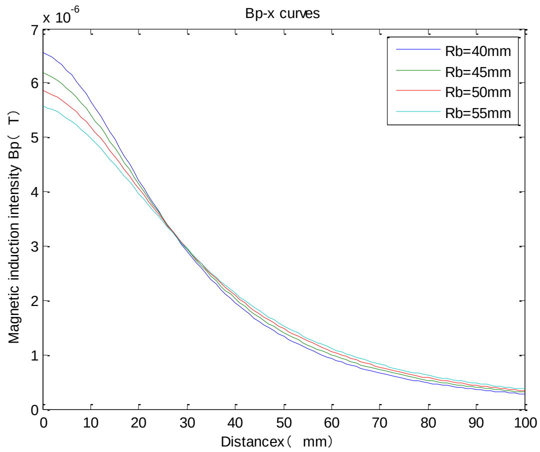

Fig 6 B - x curve of different outer radius of coil

The figure shows that 40, 45, 50, 55 mm outer radius of coil can be satisfied in the 20 ~ 40 mm with good linearity requirements, but the greater the outer radius of coil, the linear range of larger, magnetic field intensity in distant place.

B. Thickness of the coil

In the case of other parameters constant, change the thickness of the coil, the parameters in Table Ⅱ generations into calculation in (2), and draw its curve B - x, as shown in Fig 7.

Table Ⅱ Different thickness of the coil parameters

Number	R_b (mm)	R_a (mm)	c (mm)
1	55	36	10
2	55	36	5
3	55	36	3

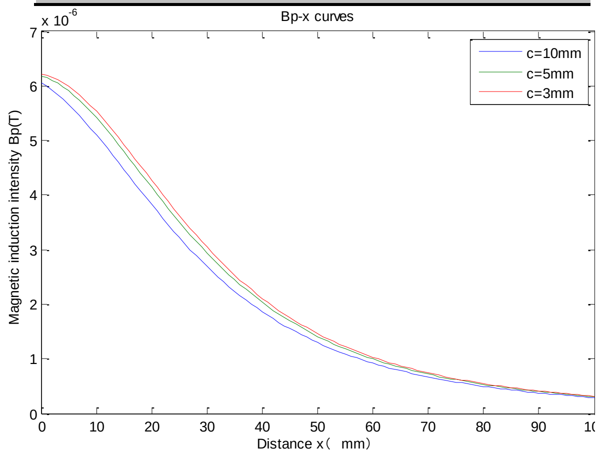

Fig 7 different thickness of coil B - x curves

The figure shows that the thinner the thickness of the coil, its sensitivity is higher, the thickness of 5 mm and 3 mm coil sensitivity gap is not big, considering the coil winding process, can choose the thickness of the coil is 5 mm.

C. Inner radius of coil

In the case of other parameters constant, change the inside radius of coil, the parameters in Table Ⅲ generations into calculation in type (2), and draw its curve B - x, as shown in Fig 8.

Table Ⅲ Different diameter coil parameters

Number	R_b (mm)	R_a (mm)	c (mm)
1	55	30	5
2	55	35	5
3	55	40	5
4	55	45	5
5	55	50	5

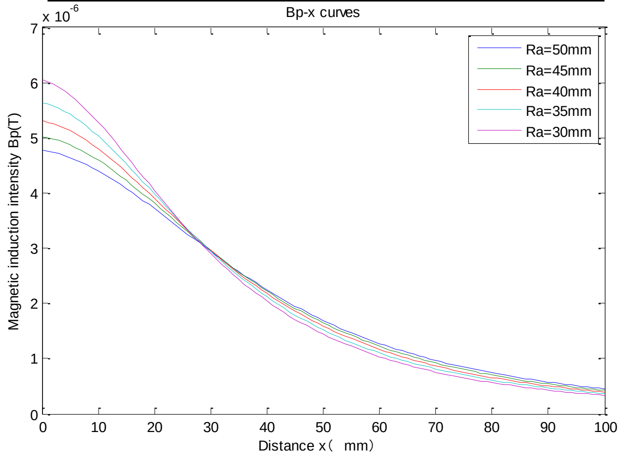

Fig 8 B - x curves of different inner radius coil

The figure shows that the coil diameter change, only near the coil, its sensitivity is slightly change, and change is not big, therefore, the change of the coil inner radius influence on sensitivity and linear range of the sensor is not big, inside radius parameters conform to the requirements in Table Ⅲ.

III. NUMERICAL ANALYSIS OF EDDY CURRENT SENSOR

After analytical design, using ANSOFT MAXWELL electromagnetic field simulation software for the numerical analysis of eddy current sensor coil parameters, analysis of coil diameter, diameter, and thickness change impact on linear range and sensitivity of the sensor.

Modeling analysis, only change the outer radius of coil, the parameters such as shown in Table Ⅰ, the numerical analysis for different outer radius, the axial magnetic field coil Bz(Bz is magnetic field intensity on the axis) curve along with the change of distance x, as shown in Fig 9.

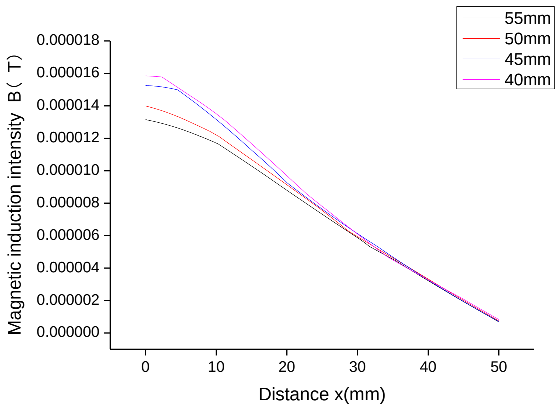

Fig 9 different outer radius coil Bz - x curves

The figure shows that in the near distance, outer radius of coil, the greater the axial magnetic field strength is smaller, but the change of the axial magnetic field is not large, namely the impact sensitivity; After a distance of 20 mm, the axial magnetic field intensity uniformity.

Only by changing the thickness of the coil parameters such as shown in Table Ⅱ, the numerical analysis of different thickness, axial magnetic field coil Bz curve along with the change of distance x, as shown in Fig 10.

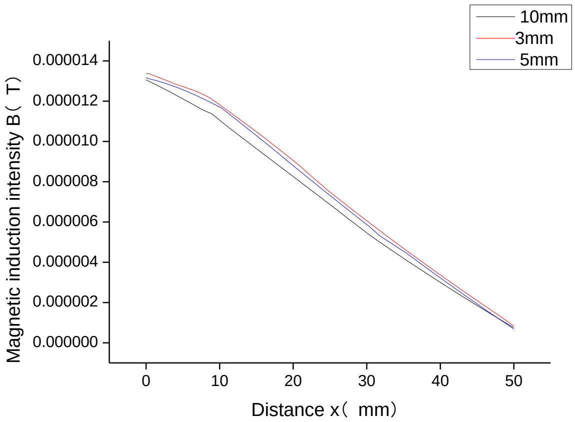

Fig 10 Bz - x curves of different thickness of the coil

As shown, the thinner the thickness of the coil, the axial magnetic field intensity, the greater the higher sensitivity.

Only change the inner diameter of the coil, the parameters in Table Ⅲ to 40, 45, 50 mm inner diameter coil parameters, the numerical analysis for different diameter, the axial magnetic field coil Bz curve along with the change of distance x, as shown in Fig 11.

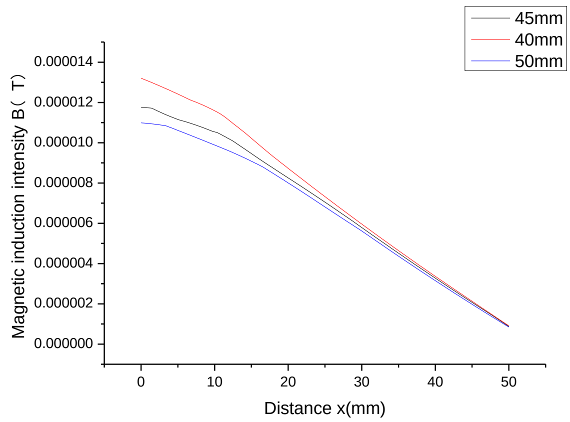

Fig 11 Bz - x curves of different inner radius of coil

As shown, the smaller the diameter of coil, and close the place of the axial magnetic field strength, the greater the sensitivity is higher, but little change. The coil diameter changes for distance measurement sensor; there is no effect on the sensitivity and linear range.

IV. CONCLUSION

In this paper, based on the research of the Biot-Savart Law and theoretically deduced formula of rectangular section coil axial magnetic field strength on the eddy current sensor design, satisfied detection requirement of eddy current sensor coil parameters; According to the parameter modeling, electromagnetic fields to make numerical analysis; Between the results of numerical and analytical design through design analysis shows that the results of numerical analysis and analytical calculation results are consistent, which can prove the correctness of the analytical design method and the correctness of the numerical analysis model, using the method of eddy current sensor for the future design and the influence of design parameters analysis provide some guidance.

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